Seismic Explosion Surveys of Crustal Structure and Deep Fault Zone Planned in the Kinki District, Japan

Kiyoshi Ito
Disaster Prevention Research Institute, Kyoto University, Uji 611-0011, Japan

Summary

Seismic surveys are planned in the Kinki district in 2004 under the Special Project for Earthquake Disaster Mitigation in Urban Areas. Background and tectonic features in the Kinki district are reviewed for the study of crustal structures. The planned surveys aim at revealing velocity structure and source faults of large earthquakes. There are many active faults in the north and middle parts of the Kinki district, but the deep extensions of the faults are not known. Some reflectors were detected in the middle crust. However, the relations of them with the active faults are not known from the previous studies. The Philippine Sea plate is subducting under the Kinki district, but detailed geometry is not defined from controlled source seismic surveys. The shape of the down going slab is determined from seismicity. However, the shape of the slab is possibly different from that of the subducting boundary of the plate, since most of the focal mechanisms of the shocks are strike-slip or normal fault types.

1. Introduction

More than 10,000,000 people lives in Osaka, Kobe and Kyoto areas. As seen in the disaster caused by the 1995 Kobe earthquake, large inland earthquakes attacked the civilized area in the past times. Seismic activity of large earthquakes in the area is not as high as that in the Kanto area. However, the large shocks are very shallow and the source area is very much close to the cities and towns with a large population. In general, two types of large earthquakes cause severe damage in Japanese Island. One is great earthquakes which occur along the trench or trough in the Pacific Ocean. Another is large onshore earthquakes in the inner zone of inland area. Although the earthquake energy of the former shocks is one order of magnitude larger than the latter ones, damages by the latter ones are nearly the same or larger than the former ones.

Therefore, it is necessary to define the fault geometry of active faults and the shape of the down going slab to estimate the strong motion prediction in the Kinki district, particularly in the urban areas.

In this report, we first describe the seismicity and
tectonic features of the Kinki district and then show the outline of the seismic surveys.

2. Tectonic Features in the Kinki District

Major tectonic factors in the Southwest Japan are shown in Fig.1. The Philippine Sea plate is subducting along the Nankai trough towards northwest direction. Seismic activity in the upper mantle with depths of 20 to 90km shows clear subduction. However, the northern edge of the seismogenic zone has a complicated shape along southwest Japanese Islands. The great 1944 Nankai and the 1946 Tohnankai earthquakes are located from under southern Kii Peninsula and Shikoku Island to the Nankai trough.

Figure 2 shows seismic activity in the Kinki District for the data of Japan Meteorological Agency (JMA) during Oct., 1997 - Dec., 2003. As described above, two types of earthquakes occur in this region; shallow shocks indicated by blue dots and events in the upper mantle associated with the subduction of the Philippine sea plate indicated by red dots. Moreover low frequency earthquakes or low frequency tremors were found in a zone parallel to the Nankai trough, as indicated by yellow dots (Obara, 2002; Ohmi, 2002).

Active faults are also shown in the Fig. 2. There are many active faults in the northern and central Kinki district, in the north of the Median Tectonic Line (MTL). The MTL is trending east-northeastern direction and the Arima-Takatsuki Tectonic Line also the same direction with an interval distance of about 60km. Other faults tending north-south direction are located in the central Kinki district. The spacing of two faults is sometimes less than 5-10km located both sides of the mountain range. Since they are reverse faults with opposite dip directions at angle of about 45 degrees, they should intersect at depth of about 5-10km.

3. Seismic Studies in the Kinki District

Several seismic studies have been carried out in the Kinki district since 1957, mainly by the Research Group for Explosion Seismology (RGES). Summary of the experiments by RGES are given by Yoshii (1994). Figures 3a and 3b shows shots and stations in the topography map. Figures 4a and 4b indicate composite plots of their all travel times for each experiment.

As shown in Fig.4, a layer with a P-wave velocity of about 6km/s is located in all areas in the upper crust. In particular, the scatters of the travel times are very small in the northern Kinki district. This indicates that the P-wave velocity is nearly constant of about 6km/s
and overlaying surface layer is not changed from place to place. This is partly because the measure lines are set in the mountainous areas or on rock sites, not in the plains where ground noises are high. The intercept times of the 6km/s travel time are less than about 0.5s, which shows the surface layer with a velocity less than 6km/s is shallower than about 5km.

However, as seen in the travel times of 2001 experiment n the Tokai-Chubu district (Fig.4b), the travel times show large scatters and are different for each shot. The measure line crosses the plain in the northern part and the travel time delays are caused by thick and low velocity sediment layer in the plain. The intercept times of the 6km/s layer are larger than in those in the Kinki district.

The middle and lower crusts as well as Pn velocity are not clearly determined from these travel times. However, a rough image of the entire crust and uppermost mantle has been obtained from the experiments (Sasaki et al., 1970). A layer with P-wave velocity of about 6.6km/s lies under the 6km/s layer of about 20km thick. The thickness of the lower crust is not clear but deduced as about 10-15km. The Moho depth is about 30-35km, with Pn velocity of about 7.8-8.0km/s. However, as seen in Fig. 4, the values have some ambiguity, partly because the velocity in the lower crust is not determined well from the first arrivals and partly because the data are not many enough to identify the later arrivals. Besides, the velocity in the upper crust is not also clear in the lower part of it.

Some reflectors were found both from controlled seismic surveys and earthquakes in the middle crust. Remarkable one is located at depth of about 20-25km. Since the cutoff of the seismicity in northern Kinki district is about 15-20km (Ito, 1992), the reflector is apparently deeper than the cut off of seismicity. In recent studies, another reflector was found at nearly the cutoff depth of the seismogenic layers (RGES,
Therefore, further surveys are necessary to obtain clear images of the upper crust, in particular the deep extension of active faults.

Furthermore, travel times at distance more than 200km are not enough to determine the deep structure. In particular no data are available in the southern part of the Kinki district. Therefore, long range experiment is inevitable to define a clear image of the lower crust and the subducting Philippine Sea plate.

Apparent reflections were obtained by the experiment in 1988 in the Kii Peninsula, southern Kinki district (Fig.3b) (RGES, 1992). Figure 5 shows a normal-move-out section of the records (Yoshii, 1990). Reflections from the lower crust are well-recorded as well as the reflection from the upper boundary of the down going slab of the Philippine Sea plate. Therefore, the refraction and wide-angle reflection surveys are effective to determine the plate boundary and the discontinuities in the crust.

The other reflector at depth of about 40-60km deep is found beneath the 2000 Western Tottori earthquake of M7.3 from wide-angle reflection survey by use of dynamite (Nishida et al., 2001). The source area of the earthquake is located in the inland area and no plate boundary has been found from seismicity as well as explosion studies. Besides, the deep reflector is shallower than that of the extension of the Philippine Sea plate from southern part of Kinki or Shikoku district. The reflector is enigmatic, but may play an important role for the transmission of stress caused by plate motion in the uppermost mantle.

Gravity anomaly is useful information on the crustal structure. Figure 5 shows Bouguer anomaly (Gravity Research Group in Southwest Japan, 2001) superposed on a geological map (Geological Survey of Japan, AIST, 2003). Most of dense contours indicate faults. Gravity anomaly values decrease from south to north relating to the down going slab of the Philippine Sea plate in south Kii Peninsula. In the northern Kinki district, gravity anomaly shows complex pattern in relation to many active faults. Most of the anomalies can be explained by the thickness of the surface layer. However in the area of Lake Biwa, the value of anomaly is as low as about 60
mgal, which is reflected deeper structure as well as the deep low density sediment under the Lake.

Figure 7 is a cross section of Bouguer gravity anomaly along the planned measure line of seismic survey indicated in the Fig. 5. Focal depth distribution of earthquakes in the strip in Fig. 2 is also shown in the Fig. 7 along the same line from Sea of Japan to the Pacific Ocean. The down going slab of the Philippine Sea plate is clearly shown by the earthquakes in the upper mantle. It is also apparent that shallow earthquakes occur in the upper crust of less than 20km. Furthermore, low frequency earthquakes occur in around 35-45km deep, at around the Moho discontinuity. However the relationship of the low frequency earthquakes and the crustal structure is not well defined to date.

4. Planning of Seismic Surveys

The Special Project for Earthquake Disaster Mitigation in Urban Areas started in 2002 as a part of the plan for reconstruction of large cities and aims to improve the prediction of strong ground motion for large earthquakes, which may cause severe damage in urban areas. In the first two years, seismic surveys were conducted in the capital areas of Tokyo to clarify the source faults of large earthquakes, in particular, their configuration and physical properties. This was done by conducting several seismic surveys along several measure lines. The results show the deep structures of the source faults, for example, the source fault of the Great 1923 Kanto earthquake was clearly defined just beneath Tokyo Bay.

Fig.8 Planned measure lines of seismic surveys in the Kinki district. Numerals show years, in which the surveys are planned to be conducted.

Fig.9 Detailed planned measure lines of seismic surveys in Kinki district in 2004.

A plan for the seismic surveys in the Kinki area is shown in Fig. 8. Kyoto University is in charge of the Line A. Other lines will be conducted by ERI, the University of Tokyo. In 2004, large-scale seismic surveys, along the Line A will be conducted in the Kinki area. The more detailed planned lines are shown in Fig. 9 on the topography map. There are many active faults in the region as well as the subduction of the Philippine Sea plate. The objectives of these surveys are to determine the deep structure of the fault geometry and to determine the structures which cause amplification of seismic waves in the Kinki area. The density of active faults in Japan is highest in the Kinki area, and the strikes have three dominant directions: north-south, west-east and northwest-southeast. Therefore, it is important to determine which is the primary fault that has deep roots and either of them is dominant for large earthquake occurrences. For example, configuration of two parallel thrust faults, which are seen to have a spacing of about 10km at the surface, may be quite different at depth. They may intersect each other and one may be dominant at depth, or they may be parallel to the depth of the deep crust. These possibilities lead to differences of the deduced source geometry, which is necessary for calculating strong ground motions in urban areas. Moreover, the subduction of the Philippine Sea plate repeatedly causes great earthquakes along the Nankai trough and, with high probability; next one is predicted to occur in about 50 years. The subduction process is a major stress source for the movements of the active faults in the Kinki district. Therefore, the configuration of the
plate boundary is also very important for determining the movements of the active faults described previously.

Observations of earthquakes by a dense array stations are also being undertaken mainly along the profile lines to derive crustal structures by using the receiver function method and seismic tomography. In Fig.10, planed array stations are shown together with routine stations of high-gain, high frequency seismometers operated universities, Hi-net and JMA. Studies by converted waves from the plate boundary are also possible for the determination of plate boundaries and deep faults. The study will reveal that the seismicity in the down going slab occur in the subducting oceanic crust or in the plate itself. The passive array studies can be extended to aerial study of the structure by including the data of routine stations, such as those of the Hi-net, JMA and universities.

The project is conducted cooperatively with the Earthquake Research Institute (ERI), University of Tokyo and the National Research Institute for Earth Science and Disaster Prevention (NIED). Our institute and ERI are mainly in charge of the seismic surveys and NIED conducts deep drilling to obtain samples to compare with the results of the seismic exploration.

The results will provide data for accurate prediction of strong ground motion in the urban areas of the Kansai district.

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